A HYDROLOGIC MODEL OF ASPEN-CONIFER SUCCESSION IN THE WESTERN UNITED STATES

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RESEARCH SUMMARY

Hydrologic impacts of grass-forb to aspen to conifer succession in the Rocky Mountain area are simulated by means of a fundamental model. Model algorithms representing hydrologic processes are sensitive to vegetational changes within the subalpine vegetation zone. Reductions in water yield are predicted as the vegetation on a small Utah watershed proceeds from a grass-forb type to aspen to conifers. Streamflow changes are largely attributable to an interaction between seasonal consumption for each vegetation type and the influence of vegetation type on snowpack. The model synthesizes present understanding and provides a framework for future watershed research.

INTRODUCTION

Forests of quaking aspen (*Populus tremuloides* Michx.) are considered to be predominantly subclimax plant communities in the Rocky Mountain Region (Mueggler 1976; Bartos 1973). Mature aspen forests are most often replaced by evergreen conifers (*Abies* spp., *Picea* spp., *Pseudotsuga* spp., or *Pinus* spp.) unless some form of major disturbance occurs such as fire, disease, or clearcutting. When an overstory is thus destroyed, prolific root sprouting of aspen generally is initiated and aspen regains dominance on the site. In many areas where natural fires have been curtailed and logging has not occurred, former aspen stands are now dominated by coniferous species. More than 4.1 million acres of commercial aspen forests (Green and Setzer 1974), and possibly an additional 1.5 million acres of noncommercial aspen lands, exist in the Rocky Mountains. Resource managers are concerned that succession of sizable portions of these forests to conifers will have adverse impacts on the water, wildlife habitat, and livestock forage values of the aspen type.

Because water is a critical resource in the West, it is imperative that we accurately assess the impact that succession from aspen-to-conifer may have on water yield. The concept of ecosystem hydrology assumes complex interactions between the ecosystem and the hydrologic cycle, and that a change in one component should effect a change in the other (Huff 1971). With regard to transpiration, for example, Satterlund (1972) cited several studies that suggest "...the ecological principle that vegetation replacement by better-adapted species will continue until all favorable niches are occupied...." He concluded that "...it appears likely that maximum rates and amounts of transpiration during the drying cycle occur under climax vegetation."

It has been shown that western aspen may be expected to transpire 3 to 4 inches more water from a 6-foot soil profile than a grass-forb community on a comparable site (Johnston 1969). Douglass (1967) stated that many forest hydrologists believe well-stocked forests use the same amount of water regardless of tree species when end-of-season soil moisture deficits are examined. However, he pointed out that patterns of soil moisture depletion for hardwoods and for conifers are quite different. Because hardwoods begin transpiring later in the growing season than conifers, more water may drain through hardwood soil profiles early in the season. Thus equal soil moisture deficits under hardwoods and conifers may not represent equal amounts of transpiration. Urie (1967) studied the net ground water recharge under hardwood and conifer stands in Minnesota. He found that the net annual water yield to ground water reservoirs from hardwoods exceeded conifers by 2.6 inches. This difference was associated with a greater snowpack under hardwoods and a longer transpiration season for conifers. He found that when transpiration and ground water recharge were combined, the conifers consumed 5.7 inches more water than hardwoods on comparable sites.

In a Colorado study, Dunford and Niederhof (1944) concluded that, from the standpoint of net water available for streamflow, aspen is probably superior to conifers. A most meaningful insight to this problem was provided by Swank and Douglass (1974) who observed a 20 percent reduction in streamflow 25 years after a hardwood stand in North

Carolina was converted to pine. Such a study is needed in the West to more accurately define the actual changes in watershed hydrology where aspen-conifer succession is occurring. In the absence of such research, a watershed hydrologic model based on recognized hydrologic processes and utilizing appropriate data from past studies and modern computer technology may provide useful insights. Such a hydrologic model may be of particular value in identifying critical research needs.

A major purpose of hydrologic simulation modeling is to realistically and precisely represent a system (a series of processes) with a network of mathematical expressions (Riley and Hawkins 1975). Models are comprised of coefficients, structure, and initial conditions that interact to manipulate each piece of input data to produce a desired output. Before a model can be deemed acceptable, it must be properly identified and formulated, calibrated to mimic observed system behavior, and verified through repeated testing. Simulation models integrate the effects of a variety of subprocesses in order to provide for maximum utilization of a given information base in terms of predictive capability of system performance (Riley and Hawkins 1975).

The purpose of this study is to formulate a structural watershed hydrologic model that will integrate available knowledge relevant to the hydrologic impacts of aspen to conifer succession. Although Leaf and Brink (1975) have written a rather sophisticated subalpine hydrology model, a fundamental model sensitive to aspects of the hydrologic cycle that may be influenced by vegetation changes would be useful. The model described in this report begins to satisfy that need.

DEVELOPMENT OF ASPCON

The model describing the hydrology of aspen to conifer succession (ASPCON) consists of a series of moisture storage compartments connected by transfer equations that systematically deal with each set of input data (fig. 1). As moisture enters and interacts with a watershed, a certain amount is lost to the atmosphere via evapotranspiration, while the remainder may become streamflow or percolate deep into the soil.

Obviously ASPCON can only be as valid as the assumptions that were made as the model was constructed. Literature pertaining to hydrologic behavior of grass-forb, aspen, and conifer ecosystems was carefully reviewed; only key references are cited. The model's transfer equations were derived from research findings that varied widely in location and purpose and, therefore, often were not directly applicable. Consequently, many water movement equations must be considered educated guesses. This lack of information points out the need for definitive research that directly relates to the critical hydrologic problems associated with aspen-conifer succession.

ASPCON is a deterministic, lumped-parameter model. The watershed is treated as a single series moisture storage "tank." Model coefficients related to watershed characteristics represent averaged values. The model calculates weekly water budgets throughout 1 water-year (Oct. 1 to Sept. 30). System input includes only precipitation and average weekly air temperature. The transfer functions for moisture routing within the watershed are described below in the sequence of ASPCON's algorithmic logic.

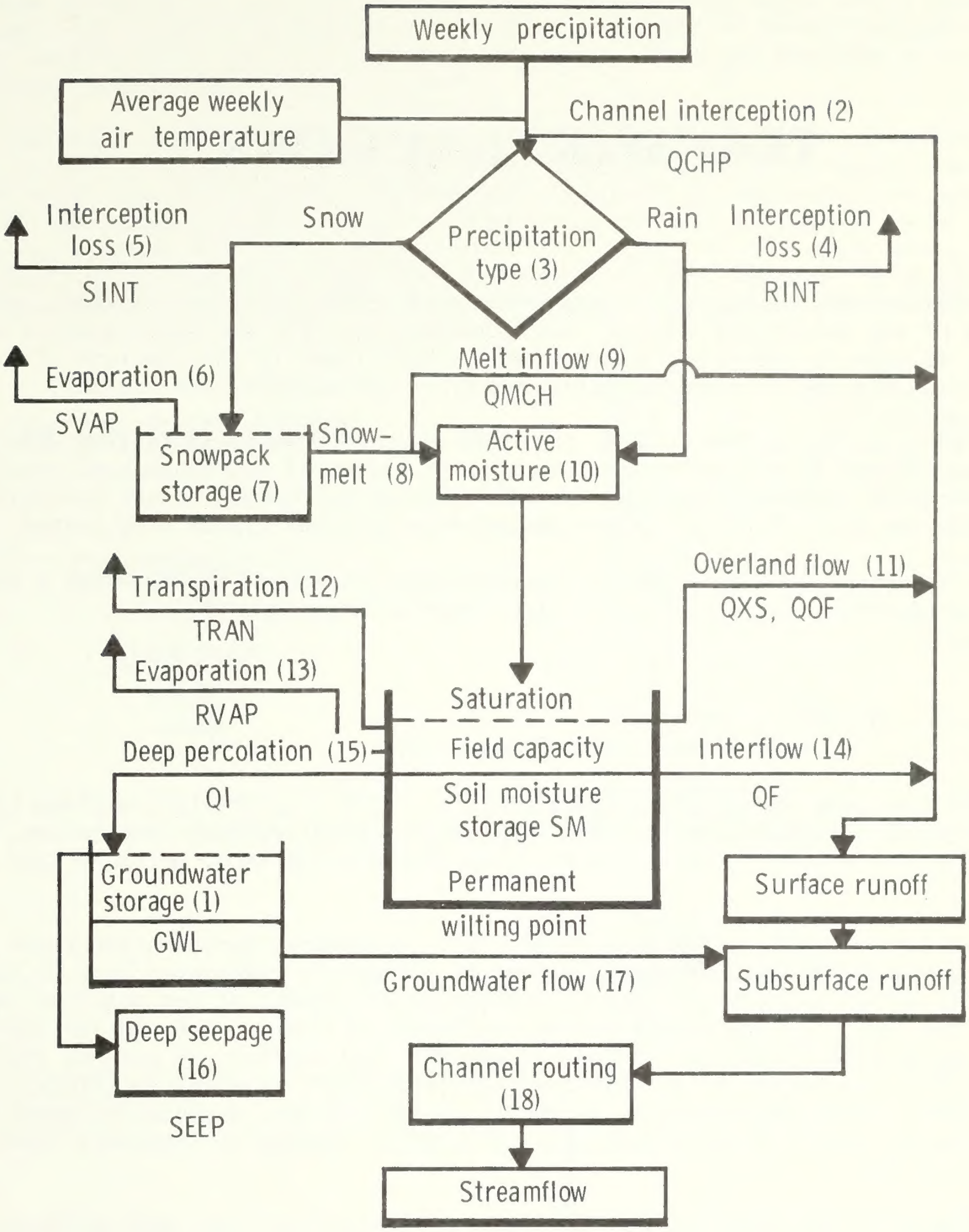

Figure 1.--Flowchart for the succession hydrology model (ASPCON). (Numbers in parentheses refer to definition given in text.)

TRANSFER FUNCTIONS[1]

1. Calculation of initial ground water level (GWL, in) from baseflow. At the beginning of the water-year (Oct. 1) average streamflow for the last rainless week of September is used to define the initial GWL. Initial GWL is the quotient of stream baseflow (in) divided by a ground water recession coefficient (AGW, in/in).

2. Channel interception (QCHP, in). The amount of moisture falling directly into the stream channel is defined as the fraction of the total watershed area consisting of surface water or saturated streambanks (ACHP, in/in) multiplied by the precipitation input. The value for ACHP may be determined from an areal map of a watershed.

3. Precipitation type. Form of precipitation is determined by using a routine similar to the model developed by the Army Corps of Engineers (1956):

$$\begin{aligned}&\text{If TEMP} < \text{TMIN, RP} = 0.0\\&\text{If TEMP} > \text{TMAX, RP} = 1.0\\&\text{If TMIN} \leq \text{TEMP} \leq \text{TMAX,}\\&\qquad \text{RP} = (\text{TEMP} - \text{TMIN})/(\text{TMAX} - \text{TMIN})\end{aligned}$$

where: TEMP is mean weekly air temperature (°F), TMIN is a critical minimum temperature, below which all precipitation is snow, TMAX is a critical maximum temperature, above which all precipitation is rain, and RP is the fraction of input moisture that falls as rain.

4. Rainfall interception loss (RINT, in). Vegetative canopies are known to intercept and retain a fraction of rainfall that is ultimately evaporated back to the atmosphere. The amount of rainfall greatly influences the amount of net moisture (moisture entering the soil) for individual storms; estimates of yearly interception losses are as follows: grass-forb, 9 percent; aspen, 12 percent; and conifer, 20 percent (Helvey 1971; Johnston 1971; and Verry 1976). The fraction of moisture received as rainfall that may be considered interception loss is assumed to be an average, weighted by areal cover of each vegetation type, of three rainfall interception storage coefficients (GSTR, ASTR, and CSTR, in/in).

5. Snowfall interception loss (SINT, in). Researchers have many different opinions about moisture loss from intercepted snow in coniferous canopies (Satterlund and Haupt 1970; Miller 1962). Estimates of the magnitude of such losses generally range between 6 and 10 percent of total snowfall (Anderson 1969). The amount of snowfall interception loss from leafless aspen is assumed to be relatively minor. The fraction of snowfall that becomes interception loss is defined in ASPCON simply as the weighted average of two interception loss coefficients, SNA (aspen) and SNG (conifer), with respective values of 0.01 and 0.07 in/in. The interception loss of snow by the grass-forb type is assumed to be zero.

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[1] Numbers correspond to the items presented in figure 1.

6. Snowpack evaporation (SVAP, in). Doty and Johnston (1969) found evaporative losses from snowpacks in winter as follows: open ground, 0.05 in/in, under aspen, 0.034 in/in, and under conifers, 0.026 in/in. A weighted average of three snowpack evaporative loss coefficients, GSV, ASV, and CSV, is assumed to be the fraction of snowfall that is evaporated during the year.

7. Snowpack accumulation. Research suggests that vegetative canopies influence snowpack in western watersheds (Gary and Coltharp 1967; Thies 1972; Dunford and Niederhof 1944; and Meiman 1970). Accordingly, snowpacks in the model are accumulated differently for each vegetative type. Snowpack accumulation is assumed to be a fraction of total net snowfall for each community type (99 percent in grass-forb areas, 106 percent in aspen areas, and 95 percent in conifer areas). This approach is simple yet does provide for a redistribution of snowfall within the watershed that is consistent with field observations.

8. Snowpack melt. Just as snowpack accumulation patterns vary between watershed cover types, the timing and rate of snowmelt may also be expected to change as a function of vegetative succession. Snowpack ablation may be expected to begin first in an open area and last in a coniferous forest. Snowmelt rates should be about the same for open and aspen areas but significantly slower for coniferous types (Thies 1972; Federer and others 1972). Snowmelt in ASPCON is indexed by mean weekly air temperature in a manner similar to the Army Corps of Engineers (1960) model. Figure 2 shows that, for each vegetative type, the amount of snowmelt is a function of a melt rate coefficient, GMC, AMC, and CMC (in/°F wk), and a base temperature coefficent, GBASE, ABASE, and CBASE (°F), for grass-forb, aspen, and conifers, as well as mean weekly temperature (°F).

9. Channel inflow from snowmelt (QMCH, in). Part of each increment of snowmelt may be expected to occur on saturated soil adjacent to stream channels and, therefore, to readily enter the stream channel. The fraction of snowmelt thus contributing to streamflow is equivalent to the product of the amount of snowmelt and a melt inflow coefficient (TMCH, in/in). TMCH functions similar to ACHP and may be estimated from an areal map of a watershed.

10. Active moisture input. The term "active moisture" is defined as the sum of net weekly rainfall and snowmelt. Active moisture is capable of entry into the soil system (depicted as the large "tank" in fig. 1) for subsequent evapotranspiration, deep percolation, or direct contribution to streamflow.

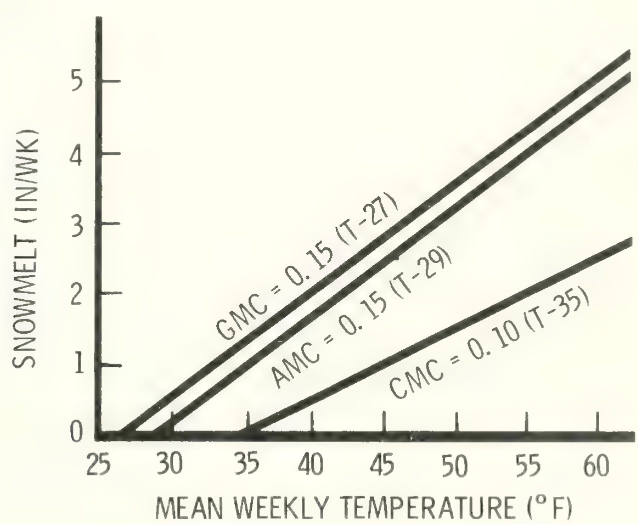


Figure 2.--Snowmelt functions for the grass-forb, aspen and conifer vegetation types.

11. Overland flow when infiltration rate is exceeded (QXS, QOF, in). The model provides for calculating overland runoff when active moisture input exceeds infiltration capacity (FI, in/wk). This condition may occur when the soil is below saturation (QXS, a rare occurrence on subalpine watersheds) or when the soil is saturated (QOF, which occurs primarily during the spring snowmelt season). Because the model is incremented on weekly intervals, QXS cannot be estimated accurately. Consequently, the infiltration capacity is set at a sufficiently large value to preclude any QXS. The model may be set for any desired increment period, which could make QXS a more important hydrologic factor.

12. Transpiration (TRAN, in). The model treats evaporation of water via plant stomates (transpiration) and evaporation of moisture from the surface soil as two distinct processes. To reflect the differences between grass-forb, aspen, and conifer communities that are suspected to influence TRAN, the following relationship is assumed:

TRAN = f (potential evapotranspiration, seasonal plant activity, plant rooting depth, community crop coefficient).

a. Potential evapotranspiration (PET, in) is calculated according to the model described by Blaney and Criddle (1962).

b. Plant activity index (PAI). Although aspen and conifers have been shown to be comparable in terms of end-of-season soil profile moisture content (Brown and Thompson 1965), there is little direct research that describes relative year-round-consumption patterns. Several researchers have found that conifers may actively transpire water at times of the year when deciduous tree species are dormant (Swanson 1967; Owston and others 1972; Smith 1975; and Urie 1959). Accordingly, a plant activity index (PAI, fig. 3) is defined as that fraction of peak activity that a plant community

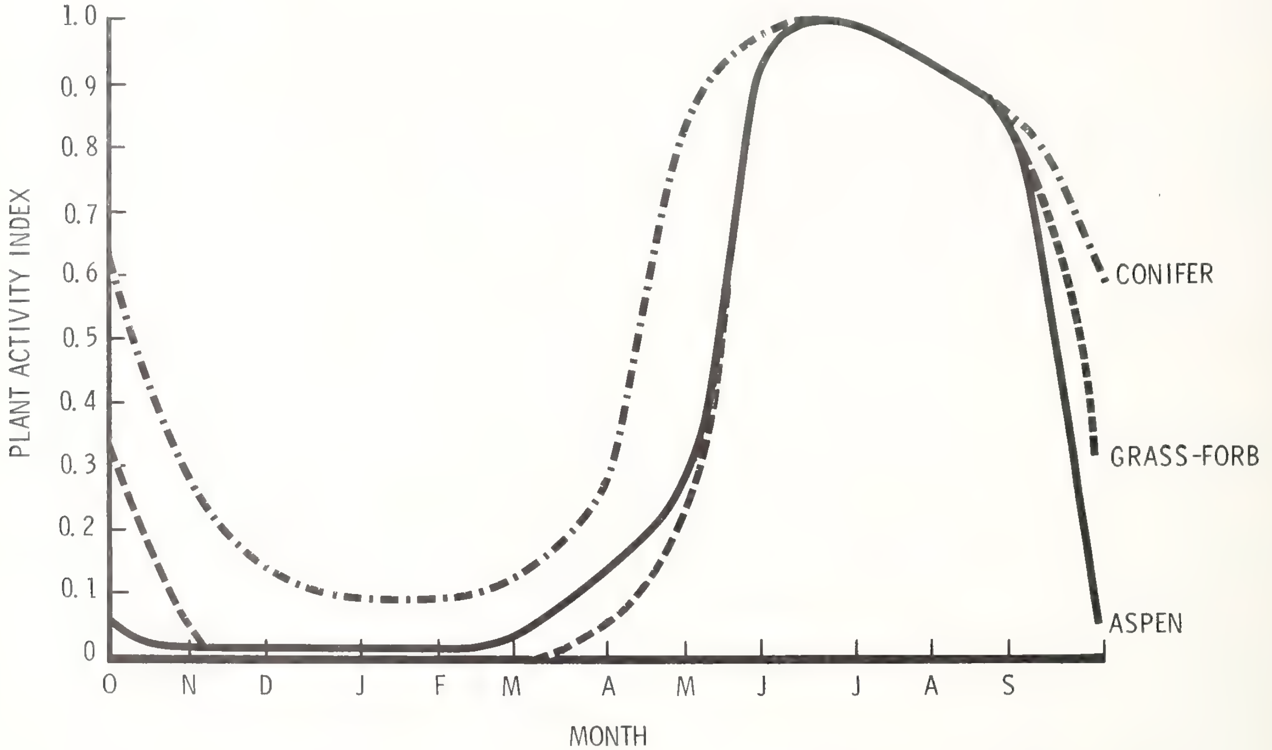
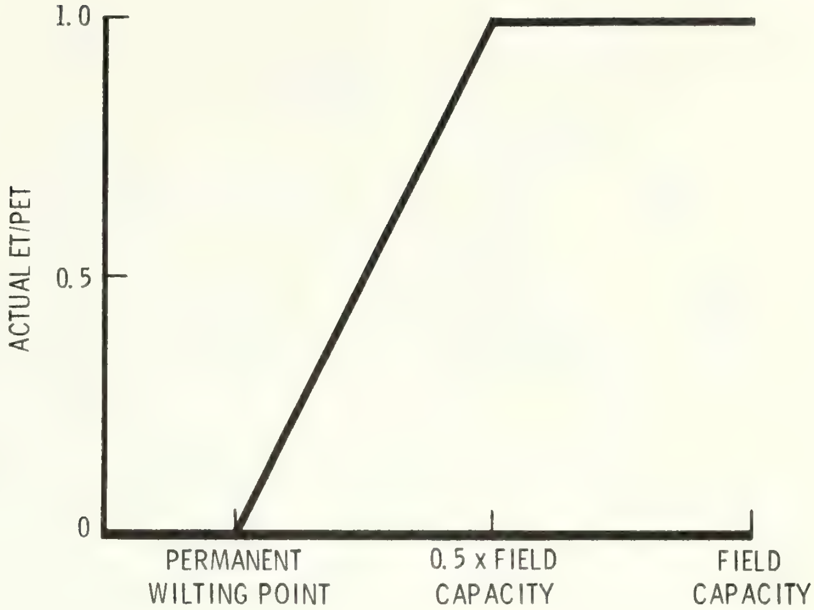


Figure 3.--Plant activity index for the grass-forb, aspen, and conifer types.

Figure 4.--Effect of limiting soil moisture on potential evapotranspiration.



may reach when water is not limiting growth. The PAI is thus defined to reflect the week-to-week influence of day length and soil temperature on a plant's ability to transpire water.

A correction is applied to PET to account for the effects of limiting soil moisture on transpiration. The relationship outlined in figure 4 adjusts PET according to the following rule: PET' = PET × (SM-PWP)/AWH where: SM is volumetric soil moisture content (in), PWP is water content at permanent wilting point (in), and AWH is one-half of the profile's available water or the difference between the water content at field capacity (FC, in) and PWP. The adjustment of PET for limiting soil moisture is made according to a model by Hanks (1976), which is similar to the approach taken by Leaf and Brink (1975).

c. Plant rooting depth (RDP). The capacity of different plant communities to occupy the root zone and the differences in mean soil depths for different watersheds are reflected in a plant rooting depth coefficient. The RDP is defined as that fraction of the total available rooting zone in the soil profile that contains 90 percent of all live plant roots.

d. Community crop coefficient (CC). The crop coefficient is included in the model to reflect differences in consumptive use rates of water by different vegetation types when all other factors are held constant. The grass-forb community is given the value of 0.9. Although forested communities may be expected to transpire greater amounts of water than nonforested areas, it is questionable whether crop coefficients for aspen and coniferous forests should be different. Unlike coniferous forests, aspen forests generally have a highly productive understory which contributes to transpiration losses. However, coniferous forests have a larger leaf area index and increased quantity of aboveground biomass than do aspen forests. As a result of the above mediating considerations, the crop coefficients for aspen and conifer types are set at 1.25.

Watershed transpiration loss is weighted according to areal vegetation composition and is calculated as the product of PET', PAI, RDP, and CC values.

13. Evaporation of rainfall from surface soil (RVAP, in). The model allows for a portion of rainfall to be evaporated from the surface soil. Generally in these forests, rain that falls during the growing season readily evaporates after each storm and seldom contributes to soil moisture recharge. A function was synthesized to reflect this phenomenon:

$$AK = RAIN/PET$$

If $AK > 1$, then AK is assigned the value of 1

$$RVAP = RAIN - (RAIN \times AK)$$

where: RAIN is net rainfall (in). The value of RVAP is then subtracted from the soil moisture content. As a consequence of defining RVAP as a function of rainfall amount as well as PET, significant amounts of rain are evaporated from the soil only during the growing season.

14. Soil profile interflow (QF, in). When soil moisture is above the water content for field capacity (FC, in), moisture may move laterally through the soil profile until it reaches the stream channel. Soil moisture in excess of field capacity is multiplied by an interflow coefficient (FQF, in/in) to define interflow.

15. Deep percolation (QI, in). The quantity of water that percolates through the soil profile and enters the ground water reservoir is calculated similar to QF except that a deep percolation coefficient (FK, in/in) is applied instead of FQF.

16. Deep seepage (SEEP, in). A portion of the water entering the watershed may leave the area without contributing to local streamflow. In other words, a fraction of moisture is routed via deep seepage into aquifers. The deep seepage storage compartment receives moisture when the ground water level reaches a certain maximum (TOP, in). When this maximum is reached, the ground water level is multiplied by a deep seepage coefficient (DPSP) to calculate the amount of water added to SEEP.

17. Subsurface flow from ground water storage (QGW, in). The amount of water entering the stream channel from the ground water reservoir is defined as the product of the ground water level and a ground water recession coefficient (AGW, in/in).

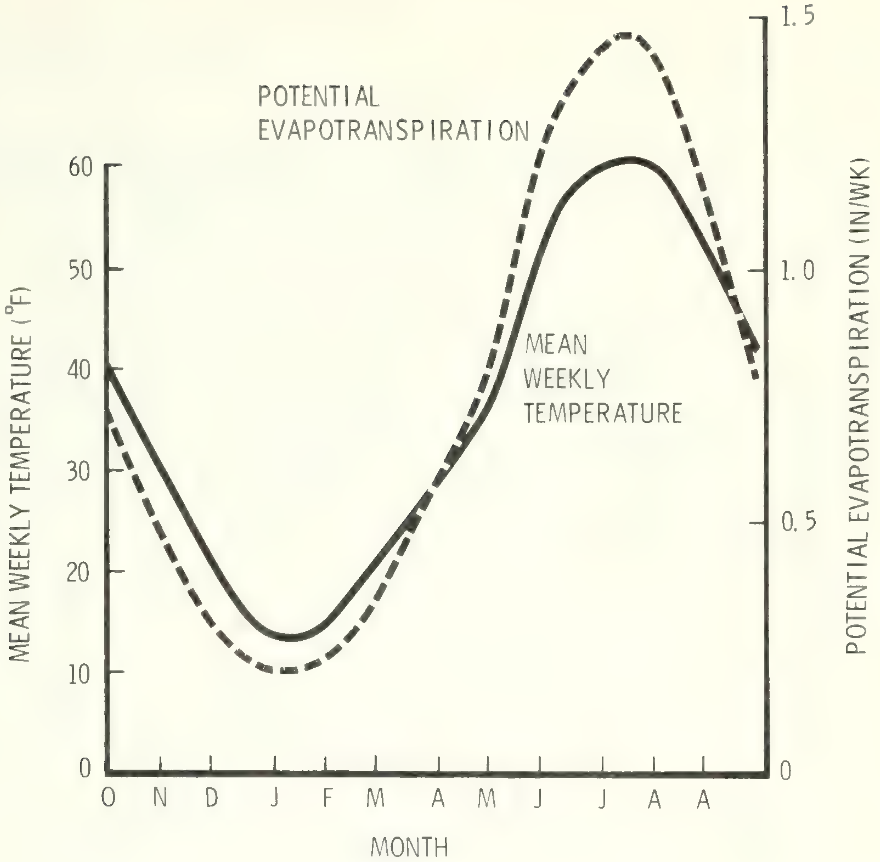
18. Channel routing of flow. Moisture for streamflow that is generated by the model may be expected to experience a timelag before passing through the gaging station at the mouth of the watershed. Therefore, the model provides for fractions of generated runoff to be delayed up to 5 weeks.

ASPCON computes weekly and yearly water budgets by summing all components of streamflow, evapotranspiration, and changes in soil moisture and ground water storage.

MODEL CALIBRATION

The model was calibrated for an "average" water-year on the West Branch Chicken Creek Watershed (CCW), Davis County Experimental Watershed in Utah. The present vegetation status on the 217-acre CCW is approximately 20 percent grass-forb, 78 percent aspen, and 2 percent conifer (Johnston and Doty 1972). A total of 47 inches of precipitation fell during the modeled year, of which 11.6 inches was rain and 35.4 inches was

Figure 5.--Mean weekly temperatures and evapotranspiration for the Chicken Creek Watershed.



snow. Average soil profile depths to limiting horizons were assumed to be 5 feet. Average weekly temperatures and potential evapotranspiration fluctuated according to the patterns shown in figure 5. A series of annual hydrographs for observed CCW streamflow were analyzed and the model coefficients in table 1 were adjusted until a predicted hydrograph was produced that agreed closely with past watershed behavior. During the calibration process, the only coefficients to be adjusted were those coefficients not easily estimated from a knowledge of watershed characteristics but to which the model is sensitive. Table 2 presents the values for model coefficients set according to the best available knowledge from the literature. The purpose of this calibration procedure is not to model CCW, but to develop a reasonable point of reference against which hydrologic changes attributable to vegetation changes may be estimated.

Once an acceptable hydrograph was obtained, all coefficients except the vegetative cover parameters were held constant throughout the remainder of the study. Thereafter, the areal cover of vegetative types on the watershed (CVG, CVA, and CVC, table 2) was sequentially altered to simulate the entire grass-forb to aspen to conifer sere. Watershed response to relatively wet and dry years was examined for five different vegetative combinations by increasing or decreasing the amount of annual precipitation. Input: wet year = 58.8 in (125 percent of normal), dry year = 35.3 in (75 percent of normal), and drought year = 23.5 in (50 percent of normal).

Table 1.--*Model coefficients manipulated during calibration*

Symbol	Definition	Units	Simulation value
SMO	Soil moisture of a 5-ft profile at beginning of water-year	in	13.5
SAT	Soil moisture of a 5-ft profile at saturation	in	24.0
FC	Soil moisture of a 5-ft profile at field capacity	in	21.0
PWP	Soil moisture of a 5-ft profile at permanent wilting point	in	10.0
FQF	Fraction of soil water (SM>FC) becoming interflow	in/in	.95
FK	Fraction of soil water (SM>FC) becoming deep percolation	in/in	.63
AGW	Groundwater reservoir recession fraction	in/in	.0012
DPSP	Deep seepage to aquifers from ground water fraction	in/in	.01
TOP	Maximum ground water level	in	28.5
CRC	Channel routing coefficients	in/in	.5, .3, .1, .1
GBASE	Snowmelt initiation temperature for the grass-forb types	°F	22.0
ABASE	Snowmelt initiation temperature for the aspen type	°F	24.0
CBASE	Snowmelt initiation temperature for the conifers type	°F	30.0
GMC	Melt rate index for the grass-forb type	in/°F wk	.25
AMC	Melt rate index for the aspen type	in/°F wk	.25
CMC	Melt rate index for the conifer type	in/°F wk	.20
TMAX	Critical maximum temperature for precipitation	°F	34.0
TMIN	Critical minimum temperature for precipitation	°F	42.0

Table 2.--*Model coefficients held constant during calibration*

Symbol	Definition	Units	Assumed value
FI	Infiltration rate	in/wk	10.0
ACHP	Fraction of precipitation intercepted by the stream channel	in/in	.0065
TMCH	Fraction of snowmelt readily entering stream channel	in/in	.0085
GSTR	Vegetation storage of rainfall for the grass-forb type	in/in	.09
ASTR	Vegetation storage of rainfall for the aspen type	in/in	.12
CSTR	Vegetation storage of rainfall for the conifer type	in/in	.20
SNA	Snowfall interception loss fraction for aspen	in/in	.01
SNC	Snowfall interception loss fraction for conifers	in/in	.07
GSV	Snowpack evaporation fraction for grass-forb	in/in	.05
ASV	Snowpack evaporation fraction for aspen	in/in	.034
CSV	Snowpack evaporation fraction for conifers	in/in	.026
ACCG	Snowpack accumulation factor for grass-forb	in/in	.99
ACCA	Snowpack accumulation factor for aspen	in/in	1.06
ACCC	Snowpack accumulation factor for conifers	in/in	.95
CCG	Crop coefficient for the grass-forb type		.90
CCA	Crop coefficient for the aspen type		1.25
CCC	Crop coefficient for the conifer type		1.25
DPG	Rooting depth coefficient for the grass-forb type		.45
DPA	Rooting depth coefficient for the aspen type		.85
DPC	Rooting depth coefficient for the conifer type		.80
CVG	Fractional area of watershed occupied by grass-forb		.20
CVA	Fractional area of watershed occupied by aspen		.78
CVC	Fractional area of watershed occupied by conifers		.02

PREDICTED HYDROLOGIC IMPACT OF SUCCESSION

Predicted weekly water budgets for the CCW were found to reflect complex interactions among assumed hydrologic processes. For example, the upper portion of figure 6 illustrates when rain and snow were received on the watershed, the lower portion of the figure shows how vegetation affects the timing of moisture entry into the soil. The timing and amount of active moisture input is a function of snowpack melt rates and

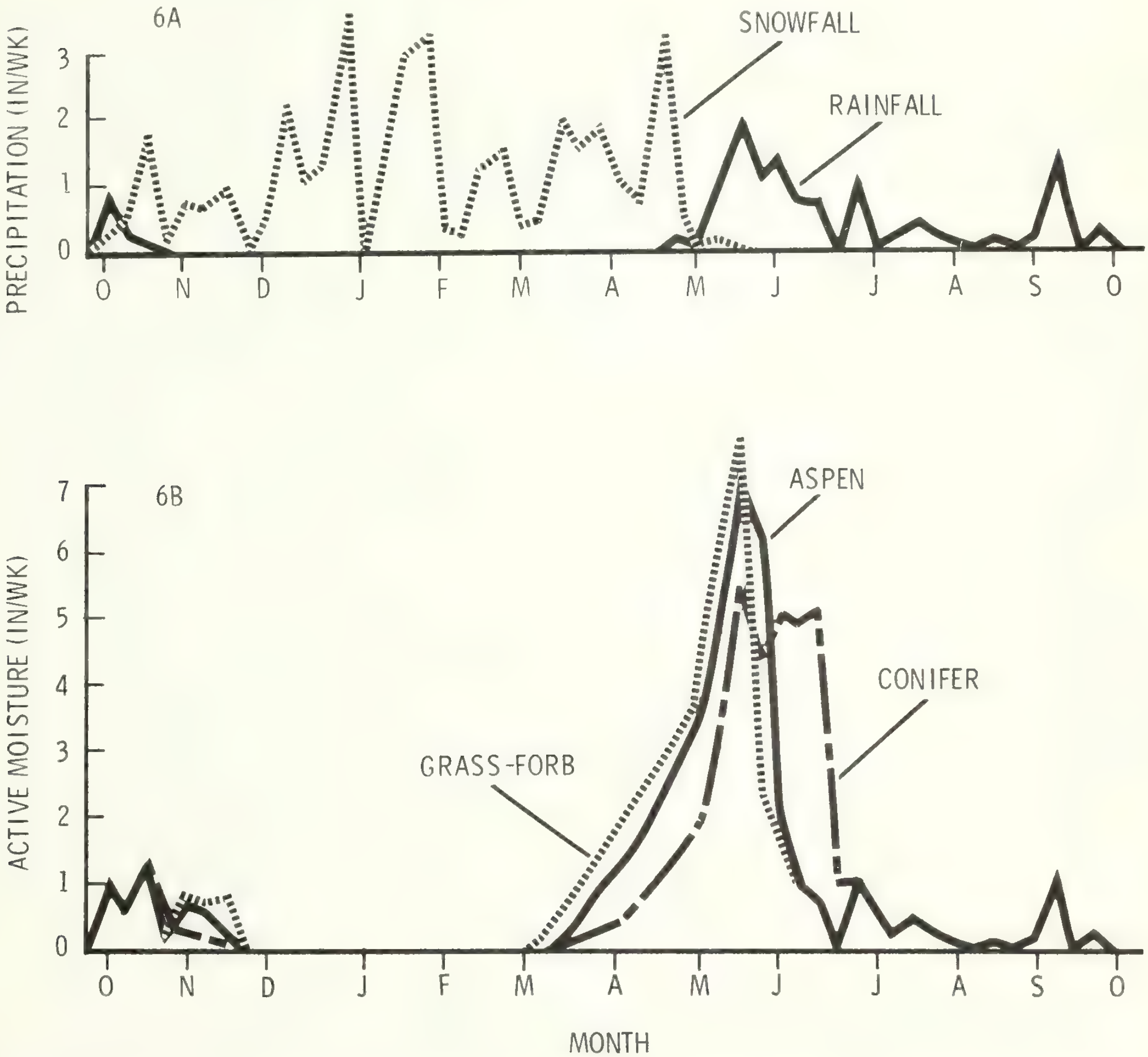


Figure 6.--Precipitation and active moisture input for the Chicken Creek Watershed.

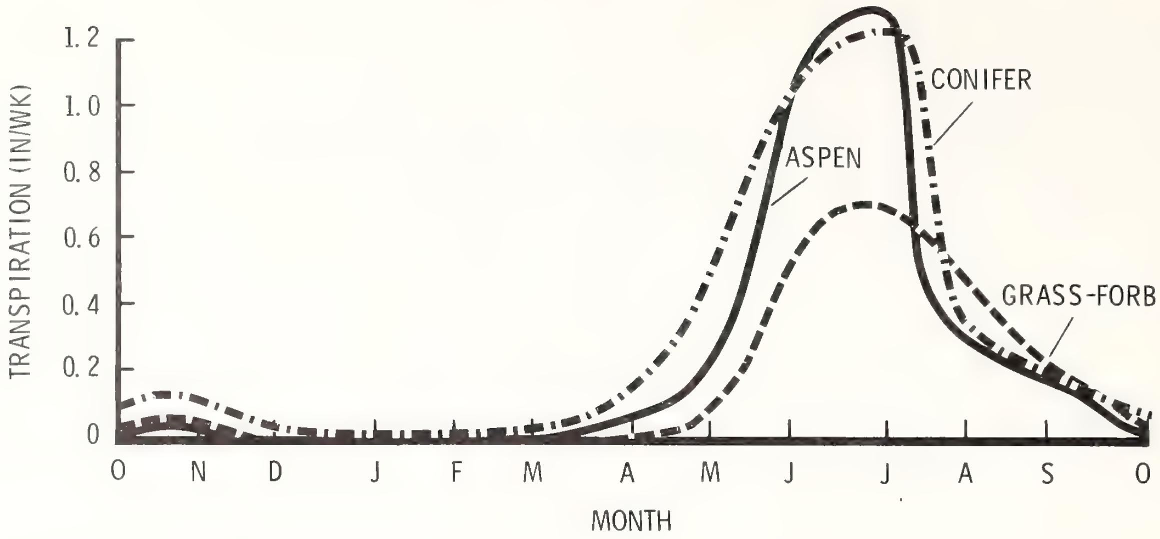


Figure 7.--Weekly transpiration patterns for the Chicken Creek Watershed when dominated by: grass-forb, aspen, and conifers.

evaporative losses (interception and soil moisture evaporation). Figure 7 presents the patterns of consumptive water use when the watershed is dominated by grass-forb, aspen, and conifer types. Greater consumptive use rates for conifer-dominated conditions may be attributed to the plant activity patterns of evergreen canopies. The combined effects of active moisture input, transpiration, and other components of the hydrologic cycle are reflected in the hydrographs in figure 8. Although the timing and magnitude of runoff under different types of vegetation cover vary substantially during the melt season, streamflow before and after the melt season is similar for all types. Dominance of aspen on a formerly grass-forb watershed causes spring runoff to be delayed slightly with lower peak flows. Spring runoff under conifer-dominated conditions is even further delayed and reduced.

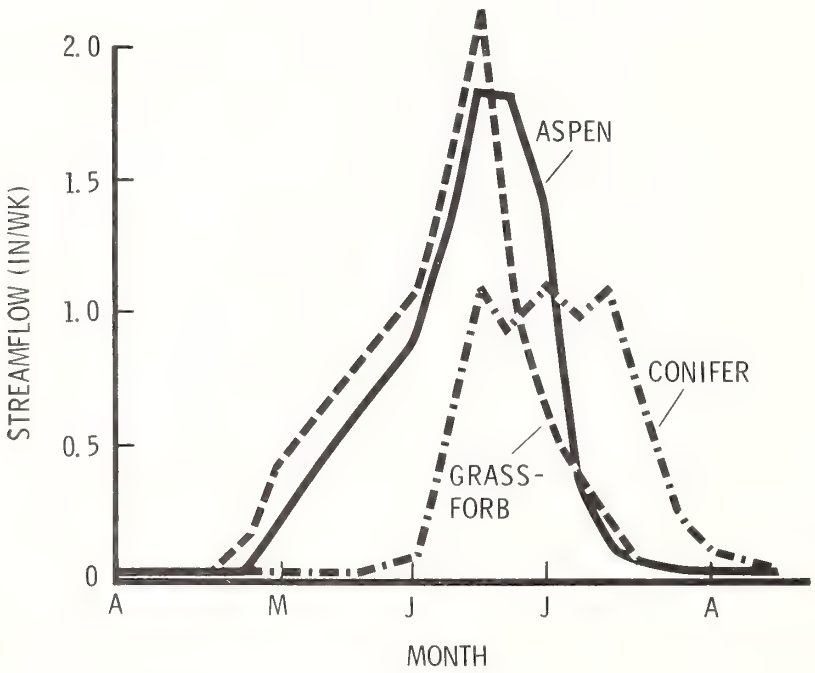


Figure 8.--Spring runoff hydrographs for the Chicken Creek Watershed when dominated by: grass-forb, aspen, and conifers.

Table 3.--*Water budget components for an average water-year on the CCW at different stages of succession*

Vegetation status[1]	Streamflow	Streamflow +ΔSM	Runoff[2]	QOF[3]	QF	ΔSM[4]	ΔGWL	SEEP	TRAN	RINT	SINT	SVAP
	Inches	*Inches*	*Percent*	*Inches*								
98-1-1	21.3	23.3	49.6	3.3	15.7	2.0	1.8	6.9	9.6	1.0	0.0	1.7
90-9-1	21.3	22.9	48.7	3.1	15.8	1.6	1.8	6.9	9.9	1.1	.1	1.7
80-19-1	20.9	22.5	47.9	3.0	15.6	1.6	1.7	6.9	10.3	1.1	.1	1.6
70-29-1	20.6	21.9	46.6	2.8	15.4	1.3	1.9	6.6	11.1	1.1	.1	1.6
60-39-1	20.3	21.4	45.5	2.7	15.3	1.1	1.8	6.6	11.7	1.2	.2	1.5
50-49-1	20.3	21.0	44.7	2.6	15.4	.7	1.8	6.6	12.0	1.2	.2	1.5
40-59-1	20.2	20.2	43.0	2.4	15.4	.0	1.9	6.6	12.7	1.2	.2	1.4
30-68-2	20.0	20.0	42.6	2.3	15.4	.0	1.8	6.6	12.9	1.3	.3	1.4
20-78-2	19.9	19.9	42.3	2.6	15.0	.0	1.7	6.5	13.1	1.3	.3	1.3
20-68-12	18.2	18.2	38.7	1.8	14.2	.0	1.7	5.9	15.2	1.4	.5	1.3
20-58-22	16.9	17.0	36.2	1.2	13.4	.1	1.6	5.5	16.5	1.5	.7	1.2
20-47-33	16.5	16.5	35.1	.9	13.3	.0	1.8	5.3	16.8	1.6	1.0	1.2
20-36-44	16.1	16.0	34.0	.7	13.1	-.1	1.7	5.2	17.1	1.7	1.2	1.1
20-25-55	15.8	16.1	34.3	.8	12.8	.3	1.8	4.9	16.9	1.8	1.4	1.1
20-15-65	15.4	15.6	33.2	.2	12.9	.2	1.6	5.2	17.1	1.9	1.7	1.1
20-5-75	15.2	15.3	32.6	.3	12.6	.1	1.8	4.9	17.4	2.0	1.9	1.0

[1]Percent watershed areal cover composed of grass-forb, aspen, and conifer types, respectively.
[2]Runoff percent is equal to (Streamflow + SM)/precipitation.
[3]See figure 1 for an identification of alphabetic codes.
[4]ΔSM and ΔGWL represent the net annual change in soil moisture and ground water level, respectively.

Predicted annual water budgets for the "average" year for different combinations of vegetation types are given in table 3. In the CCW test area, the principal sere following burning or clearcutting is visualized as less than 4 years' dominance by a grass-forb type, which is quickly followed by aspen dominance, which in turn is progressively replaced by conifers. Approximately 20 percent of the area is considered grass-forb climax, and thus stabilizes at this level. Each line in the table refers to a position assumed for the watershed on the grass-forb to conifer sere. The length of the sere is not specified, since this may vary widely from site to site. The value for QCHP is a constant value (0.314 in) for all conditions. The values for QMCH, QGW, and RVAP exhibited the following minor trends from beginning to end of the sere: 0.29 to 0.28 in for QMCH, 1.77 to 1.71 in for QGW, and 2.66 to 2.87 in for RVAP. Several components of the water budget (TRAN, RINT, SINT, and SVAP) exhibited rather consistent trends along the sere. The other values in table 3 reflect the interaction of vegetation change with the timing and amount of moisture input and moisture loss due to evapotranspiration. The value for streamflow plus soil moisture change is presented since net change from the initial soil moisture at the end of the year will affect the following year's runoff (the soil storage compartment must be recharged prior to the runoff season). The amount of streamflow reduction plus the change in soil moisture for different stages of succession are illustrated in figure 9. By the time aspen dominates the watershed, a net reduction in water available for streamflow of 3.4 in has occurred. As the watershed proceeds from aspen to climax conifer conditions, an additional 4.6 in is lost.

Annual streamflow under a variety of precipitation conditions was found to vary substantially along the successional gradient (table 4). Variable precipitation appears to alter the efficiency with which the watershed generates runoff: decreased runoff efficiency accompanies years of below-average precipitation. Late seral stages (conifer dominance) accentuate the reductions in streamflow for relatively dry years.

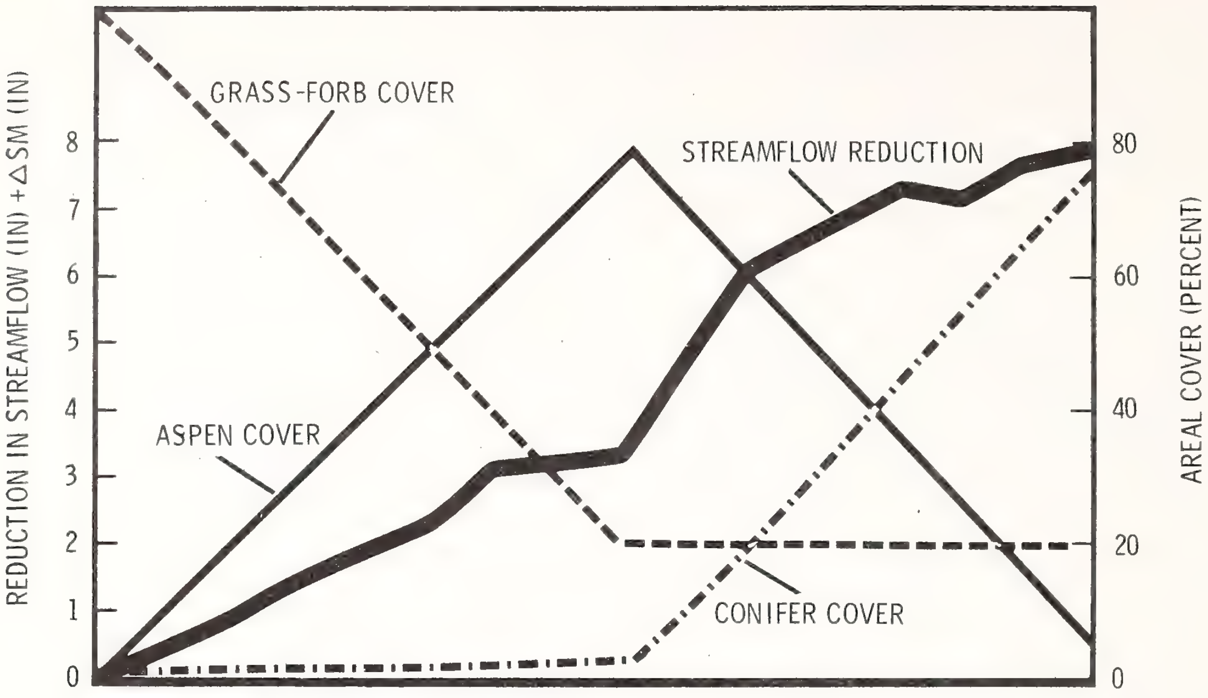


Figure 9.--Streamflow reduction +ΔSM for the Chicken Creek Watershed as a function of succession.

Table 4.--*Relationship of variable yearly precipitation to runoff (in) on the Chicken Creek Watershed*

Vegetation status[1]	Drought year	Dry year	Avg. year	Wet year
	- - - - - - - - - -	- - *Inches*	- - - - - - - - - -	- - - -
98-1-1	8.5	16.1	21.3	33.5
60-39-1	8.1	15.4	20.3	32.7
20-78-2	7.7	15.3	19.9	31.7
20-47-33	6.0	12.5	16.5	27.5
20-5-75	4.8	10.8	15.2	24.6

[1]Percent watershed areal cover composed of grass-forb, aspen, and conifer types, respectively.

SUMMARY AND CONCLUSIONS

A fundamental watershed hydrology model (ASPCON) has been presented which is sensitive to the vegetative changes associated with grass-forb to aspen to conifer succession that occurs on many subalpine watersheds in the Rocky Mountains. ASPCON represents a system of hydrologic processes that are likely to result in significant reductions in water yield for many western watersheds. The algorithms incorporated into the model were assumed from a current understanding of these hydrologic processes and a review of literature.

When applied to an actual watershed situation, ASPCON predicts a 3.4 in net loss of moisture available for streamflow when aspen dominate a former grass-forb watershed. An additional 4.6 in is lost when conifers eventually replace aspen forests on the watershed. The predicted reduction in streamflow between a predominantly grass-forb type and an aspen type is mainly a product of greater consumptive use of water and increased rooting depth of aspen. The reduction in streamflow as aspen are invaded by conifers is mainly a result of different snowmelt and plant activity patterns.

The predictive ability of ASPCON is a function of the validity of many assumed relationships. Research is urgently needed to more accurately establish the hydrologic changes attributable to aspen to conifer succession. ASPCON provides a framework capable of incorporating new information.

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